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An Optimization Algorithm for Cost Minimization in Residential Buildings

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Abstract

The increment of the electricity consumption around the world has led many efforts on the network operators to reduce the consumption in the demand side and encourage to increase the use of renewable energies. Since the buildings have a significant part in energy consumption, and lighting systems have an important role in the energy consumption of the buildings, the optimization of the lighting system should be effective. Hence, the focus of this paper is to minimize the lamps consumption of a residential house based on electricity price and try to take advantages from photovoltaic generation as much as possible. The methodology of this work is proposed as a linear optimization problem that manages the generation of a renewable energy resource, which supplies a part of the energy consumption of the house. For the case studies, the amount of the renewable energy generation, total consumption of building, consumption of the lights, and electricity price are considered.

Keywords: optimization, renewable energy photovoltaic

1. Introduction

Nowadays, the increment of electricity usage has become to a big global concern [1]. The environmental problems, such as global warming, and CO2 emissions have drawn the attention to the Renewable Energy Resources (RER) and optimization strategies [2]. A significant part of electricity consumption is dedicated to all type of buildings including commercial, residential, and industrial [3]. Currently the demand of RERs and Demand Response (DR) programs are increasing [4]. In the DR programs, consumers are emboldened to change their electricity consumption pattern based on the variation of electricity price, or technical commands from the network operators [5]. DR programs can be classified into two main incentive-based and price-based. Real-Time Pricing (RTP), Time-Of-Use (TOU), and Critical-Peak Pricing (CPP) are included in the price-based programs [6].

Due to environmental problems that have occurred aftermath of increasing electricity generation from fossil fuels, the attentions were drawn to the renewable energies [7]. Portugal also has investments on distributed generations and renewable energy. Recently in Portugal, the consumers are able to utilize the Renewable Energy Resources (RERs), consuming their own produced energy. In the past, they should inject all the generated power to the utility grid and pay for their consumption. However, with the new rules, the end-users are encouraged to consume their own produced energy [8].

In order to implement the DR programs in a building, the lighting system plays an important role. The lights are considered as dynamic and flexible loads somehow their consumption can be reduced or interrupted [9] [10].

However, the main purpose of this paper is to minimize the Electricity Bill (EB) of a residential house with optimizing the lamps consumption and interference of RERs, specially a Photovoltaic (PV) system that supplies part of power demand of the building. The lighting system of the building should be controllable for reducing the illumination. The system may consist several laboratorial and commercial equipment and instruments, such as several Programmable Logic Controllers (PLCs) and several energy meters that these technical issues are out of scope of this paper.

This paper is proposed in five sections. After this introductory section, the system description is presented in Section 2. Section 3 demonstrates the case study surveyed in this paper considering two different scenarios, and the obtained results are described in the Section 4. Finally, the conclusions of this work are presented in Section 5.

2. System Description

The proposed system regarding the optimization of lamps consumption in the residential house is based on the electricity price variation and PV generation during a day. In this way, the consumption reduction for each lamp is limited, and since any room should not lose its light completely, a minimum value of light for each lamp, have been considered. The residents of the house can define their preference for each lamp as numbers between 0 and 1 that show which lamp is more important or less.

The optimization algorithm that is used in this paper is started with definition of input data including generation of the PV, total consumption of the building, electricity price, and the detail of the total consumption of the lighting system. Algorithm needs a set point price to decide for optimizing. This set point can be defined by residences or can be calculated as the average price by algorithm. After checking the input data and conditions such as set point price and PV generation, if the desired condition is met, the optimization process is not required and should check the values again and again as long as the system is in the high consumption level or expensive price periods. Then, the program starts to optimize the consumption of the lamps to fulfill the system goal. Each lamp of the building has a priority based on its location and user preferences. After that, the required power reduction of whole lighting system, the maximum consumption reduction of each lamp, and the minimum required light intensity of each room are defined as several constraints for the proposed optimization problem.

This optimization algorithm is modeled as a linear problem which can be solved by software which has LP solver environment.

The objective function of the optimization problem is as in eq. (1):

$$\begin{gathered} Minimize \sum_{t=1}^{T}\sum_{l=1}^{L} P_{(l,t)} \times C_{(t)} \times PR_{(l)} \\ \forall\, t \in \{1, \dots, T\} \\ \forall\, l \in \{1, \dots, L\} \end{gathered} \tag{1}$$

P is the power consumption of each lamp in each time period. C is the electricity cost in each time period. PR is the abbreviation of Priority of each lamp. L and T represent the total number of lamps and time periods, respectively. The model constraints are as in eq. (2)-(4):

$$\begin{gathered} \sum_{l=1}^{L} P_{(l)} = RR \\ \forall\, l \in \{1, \dots, L\} \end{gathered} \tag{2}$$

$$0 \leq P_{(l,t)} \leq MR$$
$$\forall\, l \in \{1, \ldots, L\} \quad (3)$$
$$\forall\, t \in \{1, \ldots, T\}$$

$$0 \leq PR_{(l)} \leq 1$$
$$\forall\, l \in \{1, \ldots, L\} \quad (4)$$

RR stands for Required consumption Reduction, and MR is abbreviation of Maximum consumption Reduction that is considered for each lamp for avoiding turning off any lamp completely. As it can be seen in Eq. 4, corresponded PR for each lamp is a number between 0, and 1. The lamps with priority numbers close to 0 are the lower important lamps than lamp with priority number close to 1. It should be noted that the lamps that are considered for lighting system are able to be reduced.

3. Case Study

This section represents the case study used for verifying the proposed optimization methodology. As it was mentioned, the main purpose of this paper is to optimize the consumption of the lamps of a residential house, based on the electricity price variation. The considered house consists of three bed rooms, one living room, one kitchen, and two bathrooms, and the corridor. The overall map of the house can be seen in Fig.1. According to Fig.1, there are 10 reducible lamps in the house with 100 W maximum power consumption. Regarding the RERs, there is a PV system located at the top roof of the building, which supplies a part of the consumption of the building. The maximum capacity of PV generation is 4 KW.

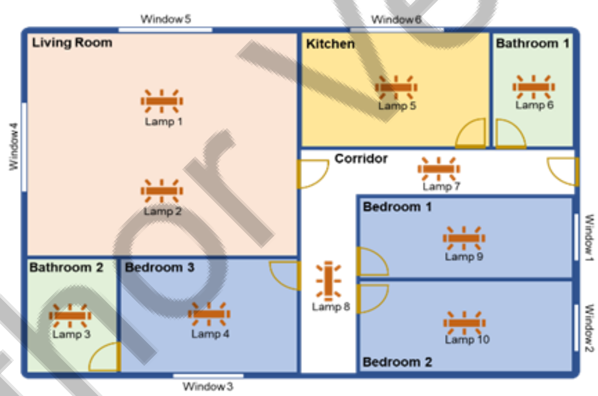

Fig. 1: Plan of the house and the lighting system.

If all the lights are turned on with the maximum intensity, the maximum consumption of lighting system in this house will be 1000 W. The total power consumption of the building, the power consumption of lighting system, and PV generation are shown in Fig. 2. This consumption profile refers to a daily profile in summer.

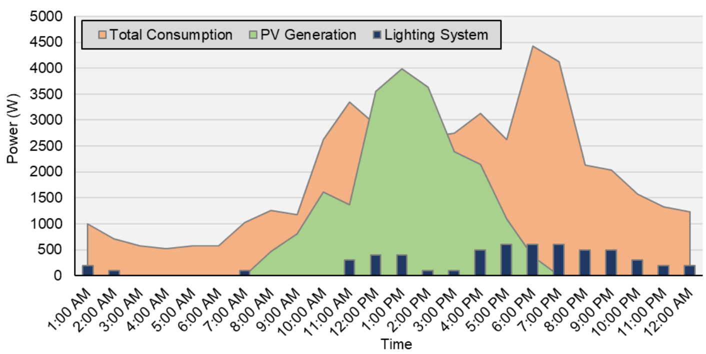

Fig. 2: Consumption and generation profile considered for case study.

As one can see in Fig. 2, the blue line indicates the part of the building consumption that belongs to the lighting system. As it is clear in Fig. 2, there are several moments that not only the PV generation (Green Columns) supplies the entire electricity demand of the building, but also the excess of the produced power can be injected to the utility grid, or store in energy storage if exist.

The electricity prices that are used for this study are the market prices for a summer day in 2018 and have been adapted from Portuguese sector of Iberian Electricity Markets [11]. The optimization algorithm checks the electricity price in each moment in order to calculate the set point price to make decision for running the optimization.

It is obvious that in the periods of day that PV generation can supply the electricity consumption completely, there is no need to reduce the lamps consumption despite the high electricity cost.

4. Results

This section represents the obtained results of proposed methodology. The consumption reduction of lighting system can be seen in Fig. 3. Also, the electricity prices are shown on Fig. 4.

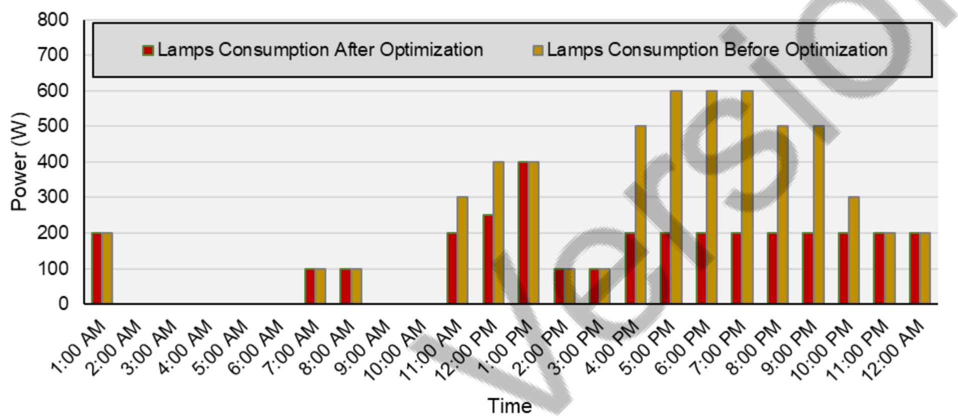

Fig. 3: Consumption and cost comparison between before and after optimization.

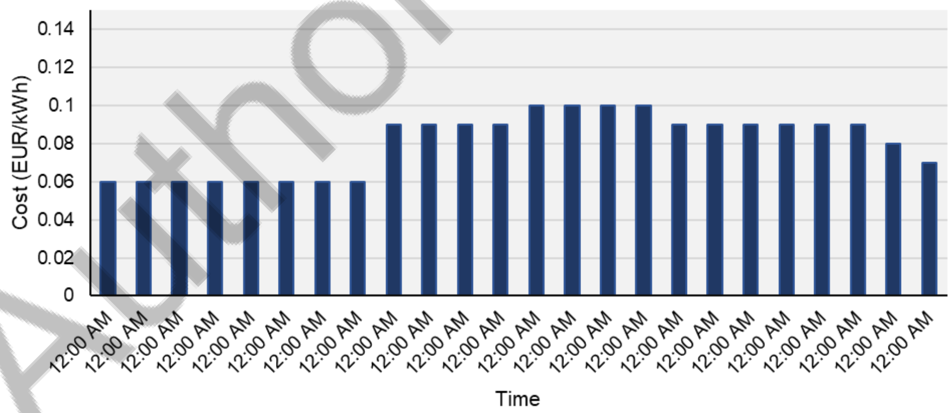

Fig. 4: The daily electricity price of a residential building.

As it can be seen in Fig.3, the lamps consumption is reduced in the expensive prices such as 11 am, and 12 am, or from 4 pm to 11 pm. There is no power reduction in some periods such as 1 pm to 3 pm which PV generation is enough for supporting the house consumption, despite the expensive electricity price. As a last result, Table 1 illustrates the effect of optimization in the energy bill of the building for one day.

As it can be seen in Table 1, the optimization process leads to reduce the energy cost of the house in one day from 0.506 EUR to 0.29 EUR, by respecting to the user's preferences.

Table 3: Accumulated costs comparison before and after the optimization (EUR).

Periods	Before Optimization	After Optimization	Periods	Before Optimization	After Optimization
1	0.012	0.012	13	0.127	0.127
2	0.012	0.012	14	0.137	0.132
3	0.012	0.012	15	0.147	0.137
4	0.012	0.012	16	0.197	0.157
5	0.012	0.012	17	0.251	0.175
6	0.012	0.012	18	0.305	0.193
7	0.018	0.018	19	0.359	0.211
8	0.024	0.024	20	0.404	0.229
9	0.024	0.024	21	0.449	0.247
10	0.024	0.024	22	0.476	0.265
11	0.051	0.051	23	0.492	0.281
12	0.087	0.087	24	**0.506**	**0.295**

5. Conclusions

In this paper, an optimization algorithm has been proposed for a residential house. This algorithm considered real-time pricing schemes and optimize the consumption of lighting system of a house in the periods that electricity price is greater than a specific value. The main purpose of the paper was to optimize the power consumption and reduce energy bill with take advantages of renewable energy resources. The presented model can be solved via several software with a linear programming solver environment.

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References

[1] L. Hernandez, C. Baladron, J. Aguiar, B. Carro, A. Sanchez-Esguevillas, J. Lloret, D. Chinarro, J. Gomez Sanz and D. Cook, "A multi-agent system architecture for smart grid management and forecasting of energy demand in virtual power plants," IEEE Communications Magazine, 2013.

[2] N. Borges, J. Soares and Z. Vale, "Multi-objective Particle Swarm Optimization to Solve Energy Scheduling with Vehicle-to-Grid in Office Buildings Considering Uncertainties," IFAC-PapersOnLine, 2017.

[3] M. Khorram, P. Faria, O. Abrishambaf and Z. Vale., "Consumption Optimization of an Office Building using Different Approaches," in IEEE Symposium Series on Computational Intelligence, 2018.

[4] M. H. Rehmani, M. Reisslein, A. Rachedi, M. Erol-Kantarci and M. Radenkovic, "Integrating Renewable Energy Resources Into the Smart Grid: Recent Developments in Information and Communication Technologies," IEEE Transactions on Industrial Informatics, 2018.

[5] O. Abrishambaf, P. Faria, L. Gomes, J. Spínola, Z. Vale and M. J. Corchado, "Implementation of a Real Time Microgrid Simulation Platform Based on Centralized and Distributed Management," Energies, 2017.

[6] P. Faria nd Z. Vale, "Demand response in electrical energy supply: An optimal real time pricing approach," Energy, 2011.

[7] H. Morais, T. Pinto, Z. Vale and I. Praca, "Multilevel Negotiation in Smart Grids for VPP Management of Distributed Resources," IEEE Intelligent Systems, 2012.

[8] G. Santos, F. Femandes, T. Pinto, M. Silva, O. Abrishambaf, H. Morais and Z. Vale, "House management system with real and virtual resources: Energy efficiency in residential microgrid," in Global Information Infrastructure and Networking Symposium (GIIS), 2016.

[9] F. Fernandes, H. Morais, Z. Vale and C. Ramos, "Dynamic load management in a smart home to participate in demand response events," Energy and Buildings, 2014.

[10] S. Rotger-Griful, R. Jacobsen, R. Brewer and M. Rasmussen, "Green lift: Exploring the demand response potential of elevators in Danish buildings," Energy Research & Social Science, 2017.

[11] "www.omie.es," Iberian Electricity Market. [Online].